A Survey of Two Dominant Low Power and Long Range Communication Technologies

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Abstract

The Internet of Things (IoT) connects various kinds of things such as physical devices, vehicles, home appliances, etc. to each other enabling them to exchange data. The IoT also allows objects to be sensed or controlled remotely and results in improved efficiency, accuracy and economic benefits. Therefore, the number of connected devices through IoT is increasing rapidly. Machina Research estimates that the IoT will consist of about 2.6 billion objects by 2020. Different network technologies have been developed to provide connectivity of this large number of devices, like WiFi for cellular-based connections, ZigBee and Bluetooth for indoor connections and Low Power Wide Area Network's (LPWAN) for low power long-distance connections. LPWAN may be used as a private network, or may also be a service offered by a third party, allowing companies to deploy it without investing in gateway technology. Two available leading technologies for LPWAN are narrow-band systems and wide-band plus coding gain systems. In the first one, receiver bandwidth is scaled down to reduce noise seen by the receiver, while in the second one, coding gain is added to the higher rate signal to combat the high receiver noise in a wideband receiver. Both LoRa and NB-IoT standards were developed to improve security, power efficiency, and interoperability for IoT devices. They support bidirectional communication, and both are designed to scale well, from a few devices to millions of devices. LoRa operates in low frequencies, particularly in an unlicensed spectrum, which avoids additional subscription costs in comparison to NB-IoT, but has lower Quality of Service. NB-IoT is designed to function in a 200kHz carrier re-farmed from GSM, with the additional advantage of being able to operate in a shared spectrum with an existing LTE network. But in the other hand, it has lower battery lifetime and capacity. This paper is a survey on both systems. The review includes an in-depth study of their essential parameters such as battery lifetime, capacity, cost, QoS, latency, reliability, and range and presents a comprehensive comparison between them. This paper reviews created testbeds of recent researches over both systems to compare and verify their performance.

Keywords: LPWAN; Internet of Things; Narrowband; Wideband; NB-IoT; LoRaWAN.

1. Introduction

The Internet of Things (IoT) and its related technologies are predicted to increase expeditiously. According to Machina Research, More than 3.3 billion devices will be connected by 2021 [8]. The Machina research prediction on M2M connections is shown in Fig. 1. The IoT aims at connecting and automating every aspect of our daily life. As shown in Fig. 2, connected devices through IoT, will influence the economy drastically [10]. Therefore, different network technologies have been developed to provide connectivity capable of supporting a large number of devices, which may be located underground, underwater or deep inside buildings. The devices will rely on a wireless connection. Technologies like WiFi based on cellular networks connect devices far from each other, in which power consumption is not limited. For connecting indoor devices which are short distanced with no power limitation, ZigBee, Bluetooth, and similar technologies are appropriate. But in case of restriction over power consumption and battery especially in long distanced communications, Low Power Wide Area Network's (LPWAN) technologies are proposed. LPWAN improves battery life and link budgets, and reduces costs compared to cellular technology [1-4]. For more clarification, a link budget makes a log by keeping all entries of losses and gains in signal propagation. A wave is attenuated via amplifiers and antennas to increase the gain product and eliminate noise. Similarly, data can be lost during propagation of a signal between the transmitter and receiver within one device or between two or more devices. Keeping track of such losses and gains is essential to calculate the reliability and efficiency of a link (through which the transmitter and receiver communicate).

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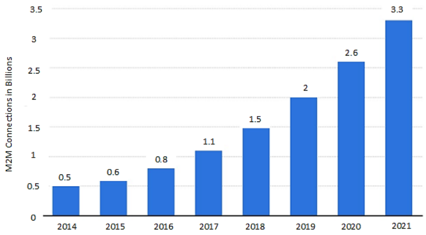


Fig. 1. Billion global connections, 2015- 2021 [8]

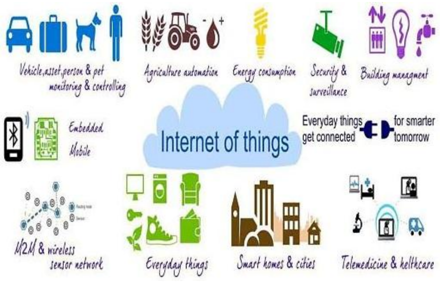
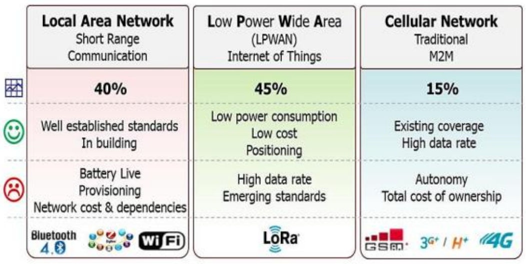


Fig. 2. Internet of Things and Implications in a Developing Economy [10]

As predicted, the IoT devices may rely on LPWAN technologies, which send data over long distance, which enables new types of services. Many technologies like LTE-MTC (LTE Advanced for Machine Type Communications), UBN (ultra-Narrow Band), Senet, Sigfox, Weightless, LoRa, and NB-IoT are supporting new LPWAN approach [4-7]. LPWAN has limitations that need to be discovered clearly. The IoT connectivity technologies segmentation is shown in Fig. 3



	Local Area Network Short Range Communication	**Low Power Wide Area** (LPWAN) Internet of Things	**Cellular Network** Traditional M2M
▦	**40%**	**45%**	**15%**
☺	Well established standards In building	Low power consumption Low cost Positioning	Existing coverage High data rate
☹	Battery Live Provisioning Network cost & dependencies	High data rate Emerging standards	Autonomy Total cost of ownership
	Bluetooth 4.0 WiFi	LoRa	GSM 3G+ / H+ 4G

Fig. 3. IoT connectivity technologies segmentation [9]

The goal of this paper is to provide a fair and comprehensive analysis of the capabilities and limitation of LoRaWAN and NB-IoT. The paper is structured as follows: Section 2 provides an overview of the technical description of LoRaWAN and NB-IoT. The critical IoT factors are compared in section 3. Next, the comparisons of measurement results are presented in section 4. Finally, the conclusion is given in section 5.

This research differs from other LPWAN-focused surveys [11-19] in that the scope of LPWA has been broadened to include the most popular, recent and distinct technologies, namely NB-IoT and LoRa, as proprietary solutions, and in that, a more clear and understandable description and a detailed direct comparison of them have been performed.

2. Technical Description of LoRaWAN & NB-IoT

Two available leading technologies for LPWAN, i.e., LoRaWAN and NB-IoT are described technically in this section. In the first one, coding gain is added to the higher rate signal to combat the high receiver noise in a wideband receiver, while receiver bandwidth is scaled down to reduce noise seen by the receiver in the second one. Different methods cause different functionality and specification for each one, which is explained in the following.

2.1 LoRa & LoRaWAN

The LoRa is a newborn technology in recent years. It can operate in non-licensed sub-1GHz frequency bands, i.e., frequency bands from 400MHz to 900MHz. Therefore, it has region specific configuration problems.

LoRa consists of two primary layers: a physical layer and a MAC layer protocol (LoRaWAN). The physical layer is based on the spread spectrum modulation scheme. An increased link budget, as well as better immunity to network interference, is achieved by deploying a derivate of chirp spread spectrum modulation (CSS) [2]. LoRa allows usage of configurable bandwidth of 125kHz, 250kHz, or 500kHz. Larger bandwidths support higher data rate, shorter time on air, but lower sensitivity. Therefore, as the bandwidth becomes wider, the resistance to channel noise, Doppler effects, long-term relative frequency and fading will increase [2,8].

The transmitter generates chirp signals by varying their frequency over time and keeping phase between adjacent symbols constant. A time domain equation of single chirp waveform is presented in (1).where $\Phi(t)$ is the phase of chirp waveform.

$$c(t) = \begin{cases} \exp(j\Phi(t)) & -\frac{T}{2} \leq t \leq \frac{T}{2} \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

LoRa modulation depends on

- Coding rate (CR), a measure of the amount of forwarding error correction;
- Spreading factor (SF), a ratio between the chip rate and the underlying the symbol rate (7-12);
- Bandwidth (BW), the frequency interval (125kHz-500kHz).

The LoRaWAN specification of different countries is summarized in Table. 1. The communication going from an antenna to nodes is called downlink, and when it is going from a node to an antenna is called uplink.

Table 1. LoRaWAN specification of different countries [9].

	Europe	*North America*	*China*	*Korea*	*Japan*
Frequency Band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	865-867MHz
Number of channels	10	64+8+8	In definition by Technical Committee		
Channel BW Uplink	125/250kHz	125/500kHz			
TX Power Uplink	125kHz	500kHz			
TX Power Downlink	+14dBm	+20dBm			
TX power Downlink	+14dBm	+27dBm			
SF Uplink	7-12	7-10			
Data rate	250bps- 50kbps	980bps- 21.9kbps			
Link Budget Uplink	155dB	154dB			
Link Budget Downlink	155dB	157dB			

LoRaWAN is the MAC layer above the LoRa. The LoRaWAN's architecture is based on a star topology.

Multiple LoRa End devices are connected to Gateways. In Europe, LoRaWAN's are limited to 10 channels, has duty cycle restrictions, without channel time limitations. LoRa WANs in North America have 64 channels. LoRaWAN network layers are shown in Fig. 4.

LoRaWAN supports three different classes. Class A must be supported by all end devices, and it has the lowest power consumption [2,9].

- Class A of end devices allows bi-directional communications. An uplink transmission is followed by two downlinks receive windows.
- Class B of end devices opens other receive windows at scheduled times.
- Class C of end devices has continuously- open receive windows.

LoRaWAN communication profile classes are shown in Fig. 5.

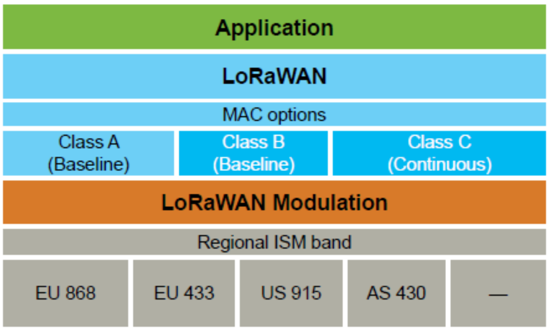


Fig. 4. LoRaWAN network layers [9]

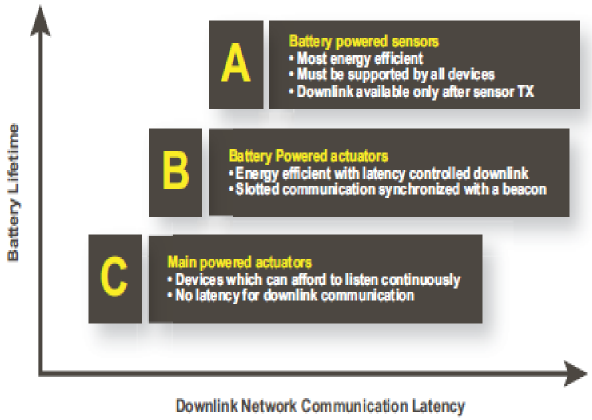


Fig. 5. LoRaWAN communication profile classes [9]

2.2 NB-IoT

NB-IoT is a simple subset of long-term evolution (LTE) standards suitable for IoT. NB-IoT does not have many features of LTE such as dual connectivity, channel quality measurement, etc. to be simple, chip and low power, which is a necessity for IoT. It uses sub-1GHz licensed frequency bands, i.e., frequency bands from 400MHz to 900MHz and employs QPSK modulation [1]. Narrowband modulation techniques encode the signal in a narrow bandwidth and share the overall spectrum very efficiently between multiple links. Moreover, it lowers the noise level inside a single narrowband and hence provides a high link budget. This modulation scheme needs no processing gain, resulting in simple and inexpensive transceiver design. The architecture of NB-IoT network is shown in Fig. 6.

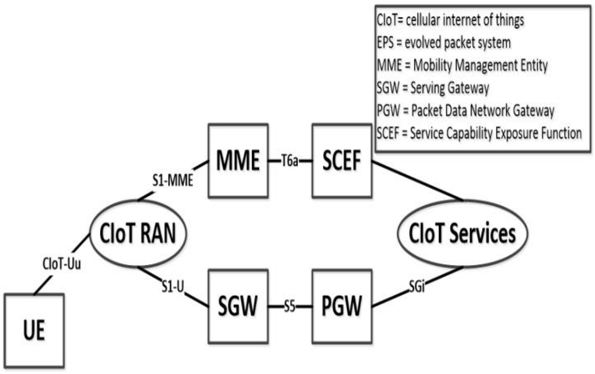


Fig. 6. NB-IoT network architecture [10]

As expected, NB-IoT core network is based on the evolved packet system (EPS) similar to LTE. Two optimizations for the cellular IoT are additionally defined, which are the user plane optimization and the control plane optimization [2]. Both planes choose the best path for user and control data packets, for uplink and downlink data. The cell access procedure of an NB-IoT user is also similar to that of LTE. Therefore, as LTE is already widespread in the US, IoT is generally based in NB-IoT there [10]. Fig.7 shows message flow for Random Access Channel (RACH) procedure Utilized by NB-IoT.

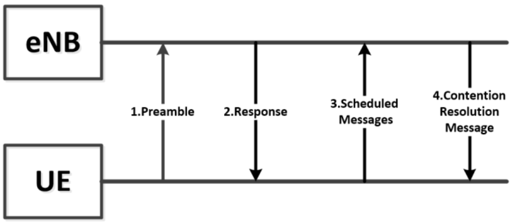


Fig. 7. NB-IoT message flow for RACH procedure [10]

3. Comparison of IoT Factors

Many factors should be considered to choose the suitable technology for an IoT application, such as quality of service (QoS), battery lifetime, latency, capacity, deployment model, coverage, range, cost, and security. These factors are discussed in this section based on section 2 and Table 2, which summarizes some features of NB-IoT and LoRaWAN.

Table 2. Some Features of LoRaWAN and NB-IoT [1, 4-7].

Parameter	***LoRaWAN***	***NB-IoT***
Spectrum	Unlicensed	Licensed
Modulation	Chirp Spread Spectrum	QPSK
Bandwidth(kHz)	125-500	25-180
Peak data rate in up-link(kb/s)	290-50	204.8
Latency(s)	Multiple of 10	<10
Range(km)	<15	<35
Power efficiency	High	Medium
Deployment model	Network operators and small companies	Network operators
Cost	Medium	High
Security	Medium to high	High

3.1 QoS

Although LoRaWAN uses chirp spread spectrum modulation to avoid interferences, noise, multipath fading and shadowing phenomena; it cannot provide the best of service quality due to the unlicensed frequency band and asynchronous protocol utilization. On the contrary, NB-IoT uses licensed frequency band, and its synchronous timing windows protocol is optimized for best possible QoS. Worth to mention that NB-IoT has more cost compared to LoRaWAN, to provide improved QoS [1].

3.2 Battery Lifetime and Latency

End nodes in LoRaWAN are asynchronous and only communicate whenever they have some data to send to gateways. This kind of protocol is called “ALOHA." NB-IoT uses a synchronous protocol in which, nodes are periodically turned on to check whether they have new data to send or not. This synchronizing consumes a significant portion of power and shortens the battery lifetime. Therefore, LoRaWAN consumes less power. Some neglect this good aspect only due to its little more latency caused by the long process of demodulation, which is not correct. In other words, comparison revels that for high data rate and low latency applications, NB-IoT is a better choice while LoRaWAN suits applications in need of longer battery lifetime but not soon data arrival more [8,9].

3.3 Capacity

Some may misunderstand and conclude waste of frequency band due to LoRa modulation rather than NB-IoT. They must pay attention to another fact that LoRa utilizes different spread spectrums to send some signals through a channel simultaneously, which increases capacity. For more clarification, assume a narrow band system with the bandwidth of 125 KHz with a rate of 1.2 Kb/s. In the first scenario (i.e., NB-IoT communication), 12 channels of narrow band width FSK modulation with the data rate of 1.2 Kb/s results in the capacity of 14.4 kb/s according to equation 2.

$$\mathrm{Capacity_{ch}} = \mathrm{Number_{ch}} \times \mathrm{BR_{ch}} \quad (2)$$

Where BR and ch stand for bit rate and channel, respectively.

While in the second scenario (i.e., LoRa communication), still with the usage of same bandwidth, the capacity of only one channel will be greater taking advantage of different spread spectrums. The capacity is calculated according to equation 3 and equals $21.531\mathrm{Kb/s}$.

$$\mathrm{Capacity_{ch}} = \mathrm{Number_{ch}} \times (\mathrm{BR\ of\ SF12{:}\ 6}) \quad (3)$$

Where BR of SF 12:6 stands for the bit rate of each spreading factor from SF=12 down to SF=6. These bit rates are equal to 293, 573,976, 1757, 3125, 5468 and 9375 b/s respectively.

As a result, LoRa modulation can increase channel capacity up to 50% [2].

3.4 Deployment Model

NB-IoT is a subsection of LTE born in June of 2016. Hence, its networks can be deployed by adapting and reusing already available cellular networks; it means it is available wherever the cellular network is available and some time is needed for adaption of networks before successful deployment. Another side of the coin, LoRaWAN's ecosystem is matured and ready to be either deployed by large companies of cellular networks or small start-up companies. The LoRaWAN network architectures simpler, but the network server is more complex.

3.5 Coverage and Range

The most important advantage of LoRaWAN is its ability to cover a whole city with only one gateway or base station; for example, all around Belgium with an area of 3500Km2 is covered by only seven LoRaWAN base stations [8]. In contrary, NB-IoT is deployable only where 4G/LTE base stations are available which means it could not cover rural and the country regions. Still, NB-IoT has a wider range than LoRaWAN.

3.6 Cost

Cost is a summation of spent money on different parts such as frequency band, network, device, and deployment. For example, LoRaWAN pays less money for each gateway than NB-IoT. It does not pay any for frequency band either. However, its device is more expensive than NB-IoT's [1]. In total, LoRaWAN is less expensive.

3.7 Security

As NB-IoT adapts and reutilizes the available cellular networks, it does gain their security too. NB-IoT's standard protocol is half-close due to its network and half-open due to the open access device. In contrary, LoRaWAN's physical layer is open to all people, small companies, and large network companies which results in its unsecured inherent; therefore, to solve his issue, two layers of security to protect data of users are defined.

3.8 Gateway

The dedicated gateways are necessary for LoRa to function correctly, while NB-IoT eliminates the need for the same. So the LoRa gate ways can be a potentially extra problem. In NB-IoT, these are not required.

3.9 Operability in Private Networks

LoRa can be used by private companies in their proprietary networks, but NB-IoT can't be. NB-IoT can only be a user in public models.

3.10 Modulation & Complexity

LoRa has a specific modulation method. This modulation method is based on spread spectrum to support long range, but in the other hand, this method have lower data rate in comparison with NB-IoT modulation method. Also, there are issues about IP rights and licensing of LoRa technology. NB-IoT technology uses DSSS modulation and has lower hardware complexity in comparison to LoRa.

The direct comparison of LoRa and NB-IoT Technologies is illustrated in Table 3. From the results, we can conclude that LoRa hardware can be produced and sold at a low price, and LoRa devices have no subscription cost, but the LoRa Alliance only has limited control over the deployment of networks. NB-IoT technologies on the other hand, though the devices will have a subscription charge, the deployment of gateways is for newer grade hardware as simple as applying a software update; a country can have a functioning NB-IoT network within an hour.

Table 3. Direct Comparison of LoRa & NB-IoT Technologies.

Technology	***LoRa***	***NB-IoT***
Topologies supported	Typically Star, Mesh possible	Star
Maturity Level	Early stages- some deployment	Early Stages
Frequency Band	Sub GHz ISM bands	LTE & GSM bands
MAC Layer	ALOHA-based	LTE-based
Founded	2015	2016
Modulation Technique	Spread Spectrum	LTE-based
Proprietary aspects	Physical layer	Full Stack
Nodes per gateway	>1,000,000	52,000
Deployment model	Private and Operator -based	Operator-based
Encryption	AES	3GPP
Interference immunity	Very High	Low
Energy efficiency	Better than NB-IoT	good

4. Comparison of Measurement Results

In this section, we compare the measurement results of recent works on IoT factors. The target is to study the important factor of LoRa WAN and NB-IoT technologies in a real condition. [20] studied NB-IoT coverage and capacity for a small country side area. Also, coverage and capacity have been studied for NB-IoT [21] and LoRa [20]. In [22] the coverage of NB-IoT, LoRa, GPRS, and Sigfox has been simulated in a realistic scenario, covering $7800\,\text{km}^2$, using Telenor's commercial 2G, 3G, and 4G deployment. According to the reported measurement results, the NB-IoT is the best performing indoor solution. It has less than a 4% failure rate for ten devices, while LoRa provides 20% failure rates, which also has more sensitivity to device numbers. Therefore, NB-IoT has the best coverage and link adoption, but it has the longer time on air.

The LoRa has only one manufacturer (Semtech). Also, as the unlicensed bands become more crowded, the interference may increase. Therefore, the performance of the LoRa networks may decrease.

According to the experiment's results in [23], the lost packet number depends on SF, CR, and BW of the communication in the presence of different noise levels. The transmitter was placed 10 meters from the receiver. By changing Bandwidth from 125 kHz to 500 kHz, when the SNR is -10dBm, the packet lost increased from 1% to 30.66%. The measurement results of LoRa in recent literature are summarized in Table 4.

From the results of the recent works, summarized in Table 4, we can conclude LoRa features low data rate and long communication range. Therefore it is suitable for applications with a reduced number of messages without challenging delay constraints. While it can't be an appropriate solution for real-time applications which require low latency.

The coverage analysis has been done for NB-IoT and LoRa in [36]. Two different configurations in 800 MHz with 25 and 500 active sectors have been simulated to carry out their maximum connectivity level. The results show that LoRa covered 80% area, while NB-IoT can reach 90% of the covered area, because, NB-IoT is a licensed solution.

In [37], capacity and system efficiency analyses are performed for a massive NB-IoT system for smart metering. The simulations have done in a realistic scenario, in a rectangular area of 2000m ×1700m. In this configuration, 75% of transmitting uplinks are succeeded. And the maximum measured coverage distance is about 960m for a single receiver and transmitter configuration.

5. Conclusion

Wireless communication is the most recent industrial revolution in the last decades which is utilized for connecting devices to each other. More than twenty-five billion machines and objects which are considered as devices are expected to be connected by the year 2020. There are many challenges and factors such as connection range, data rate, power, etc. to consider to provide connectivity of these devices. Various network technologies such as local area network, LPWAN, and Cellular network is currently available. This paper has focused on the most leading wireless technology for long range and low power communication, i.e., LPWAN.

In this work, two prominent LPWAN technologies, i.e., LoRaWAN and NB-IoT are described, analyzed, and compared in depth. LoRaWAN is a coding gain method which defeats the noise of long range by a new method of modulation in its unlicensed frequency band, while NB-IoT does so by utilizing minimum possible licensed frequency band. It is shown that licensed NB-IoT has the advantage of better QoS, latency, and range, while unlicensed LoRaWAN has advantages of better battery lifetime, capacity, and cost. Therefore, the choice is strongly depending on the users' goals and necessities of each application.

Table 4. Measurement results of LoRa in recent literature.

Ref	***#Gate ways***	***#Nodes***	***BW (kHz)***	***Tx (dBm)***	***SF***	***ISM band (MHz)***	***RSSI measurement***	***Payload (byte)***	***Coverage (km)***	***Reliability measurement***
[22]	1	10	125	2,4,6,8,10,12	-	868	Done	-	$7800\,\text{km}^2$ area	Maximum Coupling Loss (MCL)
[23]			125,250,500		7,8,9,10,11			1	10m with the presence of with Gaussian	% packets lost

Ref	*#Gate ways*	*#Nodes*	*BW (kHz)*	*Tx (dBm)*	*SF*	*ISM band (MHz)*	*RSSI measurement*	*Payload (byte)*	*Coverage (km)*	*Reliability measurement*
									noise	
[24]	1	1	125,250,500		7,8,9,10,12	868		106		Packets PRR
[25]	1	1	125	20	12	-	Done	large	7 floors	RSSI value
[26]	3	2	-	14	variable	868	Done	seq. num	2.2	record ACKs
[27]	0	6	variable	17	variable	-	-	variable	0.342	packet reception rate
[28]	1	1	-	-	variable	-	-	-	2	SF for coverage
[29]	1	1	125	14	variable	868	Done	variable	0.5m-60m	# packets lost & packets error
[30]	1	1	250	-	10	868	Done	10,50,100	0.276-8.52	PER
[31]	0	7	-	-	-	915	Done	26	0.5-2.7	% valid packets received
[32]	1	1	125	14	12	868	Done	seq. num	15	% packets lost
[33]	1	1	125	14	12	868	-	-	65m-195m	%received packets
[34]	0	2	-	3	variable	2450	-	21	0.975 outdoor 30 m indoor	% valid packets
[35]	1	1	125	2/14	variable	-	Done	1,25,51	3.4 outdoor 100m indoor	% packets received & avg.throughput

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